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ABSTRACT

This paper describes research conducted in a classroom devoted to conceptual change instruction. The teacher in this class of fifth grade students at a midwestern parochial school made explicit attempts to have her students comment on the conceptions they held, their justification for those conceptions, and the status they attached to their conceptions. Findings indicate that students' comments about conceptions allowed the teacher to assess their scientific knowledge and to plan instructional activities that presented the students with additional scientific information. Comments that justified a conception allowed the teacher to identify components of the students' conceptual ecologies that inhibited conceptual change and to plan instructional activities that facilitated conceptual knowledge development for these students. As a result of the students' comments about their conceptions, the teacher's planned instructional activities focused on two specific aspects of the Conceptual Change model, namely components of the conceptual ecology and status. It is concluded that the learning environment in this classroom, created by the interaction between students' responses and planned instructional activities, facilitated the development of these students' conceptions. Contains 19 references. (Author/JRH)

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CLASSROOM ENVIRONMENT AND CONCEPTUAL CHANGE INSTRUCTION

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This paper describes research conducted in a classroom devoted to conceptual change instruction. The teacher in this class of fifth grade students made explicit attempts to have her students comment on the conceptions they held, their justification for those conceptions, and the status they attached to their conceptions. Students' comments about conceptions allowed the teacher to assess their scientific knowledge and to plan instructional activities that presented the students with additional scientific information. Comments that justified a conception allowed the teacher to identify components of the students' conceptual ecologies that inhibited conceptual change and to plan instructional activities that facilitated conceptual knowledge development for these students. As a result of the students' comments about their conceptions, the teacher's planned instructional activities focused on two specific aspects of the Conceptual Change Model, namely components of the conceptual ecology and status. The learning environment in this classroom, created by the interaction between students' responses and planned instructional activities, facilitated the development of these students' conceptions.

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CLASSROOM ENVIRONMENT AND CONCEPTUAL CHANGE INSTRUCTION

Over the past two decades research in science education has increasingly focused on student learning. Identification of students' existing conceptual knowledge, recognition of the persistence of those conceptions following instruction, and the potential impact of 'alternative' conceptions on subsequent learning (Driver & Easley, 1978) has resulted in a program of research known as conceptual change. This research program has generated collections of research describing the variety and extent of students' conceptions (Duit, Goldberg & Niedderer, 1992; Pfundt & Duit, 1991; Novak, 1987; Helm & Novak, 1983), efforts by teachers and researchers to address students' conceptions in classroom settings (Children's Learning in Science Project, University of Leeds-England (1987); the PEEL Project, Monash University-Australia (Baird & Mitchell, 1986); and various projects in conceptual change at Michigan State University-USA) and the Conceptual Change Model (Posner, Strike, Hewson & Gertzog,1982, and Hewson, 1981). The collected volumes provide the empirical basis for establishing students' conceptions as a valid area for research while the classroom interventions provide an indication of the desire teachers and researchers feel for addressing students' conceptions in the practical sense of a classroom.

The significance of this study is that it begins to examine the context within which conceptual change instruction takes place, an area not previously reported in the literature. Classroom teachers choose instructional activities for their students and present them in a manner that either promotes or discourages examination of conceptual knowledge. Even though teachers can not cause learning to occur, they can facilitate the process of conceptual knowledge development if they are aware of the conceptions their students have, the status of conceptions, and some of the reasons students give for their conceptions. Planning and executing instruction that takes into account each of these is the responsibility of the teacher. Although it is not possible to characterize uniquely all attempts at conceptual change instruction, a common

pattern has been to elicit students' ideas on a topic, have them represent their ideas (e.g. verbally, through illustrations, or in written form), confront students' ideas with a canonical view of the same phenomenon, and check to see if the students changed their ideas. This sequence ignores several of the basic tenets set out in the Conceptual Change Model, namely the importance of the conceptual ecology and the status that an individual attaches to a particular conception (Hewson & Thorley, 1989). Since conceptions are believed to survive and have meaning within various components of the conceptual ecology, and since a change in a conception must be accompanied by a concomitant change in status (Hewson & Thorley,1989), it is reasonable to assume that successful instruction directed at these aspects of the Conceptual Change Model will be more likely to facilitate change in an individual's thinking.

Recent Efforts In Conceptual Change Instruction

The outcome of programs designed to effect conceptual change have met with varying degrees of success. The following transcript, taken from Baird and Mitchell (cited in White & Gunstone,1989, p.585), is a particularly salient example illustrating the reactions of two students in a conceptual change classroom with an explicit focus on metacognition:

> S_1: 'We see what all of this is about now,' one said. 'You are trying to get us to think and learn for ourselves.'
> T: 'Yes, yes.' replied the teacher, heartened by this long-delayed breakthrough, 'that's it exactly.'
> S_2: 'Well,' said the student, 'we don't want to do that.'

These students indicate their understanding of the idea this teacher has been trying to instill within them but they have no commitment to it as a way of thinking about their own learning. In terms of the Conceptual Change Model (Hewson, 1981), they find the idea intelligible but not plausible or fruitful. This is to say that the idea of constructing your own knowledge, as opposed to receiving it from an external source perhaps, is something these students have considered but do not find to be a reasonable means of learning for them. They do not find this form of thinking

to be initially plausible (Strike & Posner, 1985, p.220) in the sense that they would want to think of themselves as constructors of knowledge or possibly even capable of constructing knowledge. The subject of this research is the manner in which one teacher encourages her students to find conceptual change instruction a plausible means of learning. What students in this classroom are thinking about is their own learning process rather than just participating in a sequence of conceptual change lessons.

Research Questions

A question that emerges from the above example is: how can a teacher engage students in thinking about their conceptions as opposed to thinking only with their conceptions? Thinking that encourages examination of conceptual knowledge as objects of cognition and of the processes by which that knowledge is justified is considered to be an important aspect in the development of scientific thinking skills as pointed out by Kuhn, Amsel and O'Loughlin (1988):

> Thinking *about* theories, and how evidence bears on them, in contrast merely to thinking *with* them, we have suggested, is a tremendously important distinction. . . . The person who only thinks with theories lacks any awareness or control of the interaction of theories and evidence in his or her thinking. The person who has achieved the ability to think about theories and how evidence bears on them has achieved a considerable degree of awareness of and control over this interaction. We have suggested that this ability is "metacognitive" in a very important, core sense of the term. (p. 228)

The current study, part of a dissertation investigating the conceptual ecologies of learners, explores the context within which a teacher facilitates conceptual knowledge development with her students. Identification of the characteristics of the learning environment and an analysis of the teaching activities presented to the students are used to answer the following research questions: 1) How did this teacher engage her students in activities that promote examination of conceptual knowledge? and 2) How did this teacher use students' comments in planning instructional activities to facilitate conceptual knowledge development?

Site Description And Data Analysis

Data to answer the above questions were collected over a period of one year through observation of classroom practices and discussions with the teacher. Observation notes taken while in the classroom, transcripts of classroom discourse and individual student interviews, teaching resources presented to students, and informal discussions with the teacher are used to describe the learning environment of this particular classroom (Note: Artifacts of transcription are illustrated in Table 1). Initial examination of the data involved identifying the instructional activities students engaged in throughout the school year. Instructional activities were placed on a large sheet of paper in chronological order. Additional data was added in two sequences parallel to the instructional activities, one for the teacher's intended science content learning objectives and one containing evidence from the students' discourse as to the conceptions they were developing (see Appendix A). Analysis of the entire data set requires interrelating these three strands: 1) a description of the instructional activity as presented to the student, 2) the teacher's intended science content learning objectives, and 3) evidence from the students of their conceptual knowledge development. The insights presented here provide a case study of how this teacher facilitated the students' conceptual knowledge development in her classroom.

The students

The students in this research were aged 10 -11 (fifth-grade) in a midwestern parochial school. The school is located in a middle class community of approximately ten thousand people with agriculture, employment in a larger community nearby, and light industry being the predominant forms of employment. Thirteen students were enrolled in the class for the entire year, six females and seven males. All students enrolled in this class were within the normal ranges of ability for fifth grade students - none was exceptionally gifted or deficient in basic skills. Students in this school receive instruction from the same science teacher each year and would continue to receive instruction from her until matriculation at the end of grade six.

Physical aspects of the classroom

The science classroom in this elementary school provided a modern setting in which to learn science, a setting typical of most classrooms specialized for the teaching of science. Black polygonal lab tables with electrical outlets, sinks, gas jets, and storage cabinets bordered either side of a large central open space. A network of computers was also available with one terminal at each lab table. A demonstration table and white board occupied one end of the classroom with collapsible storage and a preparation area at the opposite end. Atypical aspects of this classroom included a carpeted floor, on which the students often gathered in small groups to discuss their ideas, and student created posters literally covering the walls, ceiling, and demonstration table at the front of the classroom. These posters represented students' developing ideas on the content under study and were routinely produced by all grades of students. In addition to the student work currently on display, the teacher had saved all previous posters prepared by students in a storage area. Frequently the teacher retrieved these posters to remind the students of their past ideas and to encourage them to talk about how and why their ideas had changed. Although this classroom was well supplied with the equipment necessary for teaching science, there was an additional quality to this classroom that made it different as well. The students' posters, prominently displayed on all available flat surfaces, gave the impression that, in this classroom, students' conceptions were the subject of interest. Continually developing their ideas from day to day and year to year, this 'work in progress' impression stands in sharp contrast to the more typical displays of 'finished products' seen in many classrooms.

The teacher

The teacher in this classroom has taught in excess of twenty years in parochial schools and recently received a Doctor of Philosophy degree in Science Education. She is active in a number of professional organizations related to improving science education locally and

nationally, and she has received numerous awards and nominations in recognition of her teaching from state and local agencies. Her weekly schedule with the fifth grade students included three instructional periods each of 52 minutes devoted to science instruction, and one period each for health and computers. This schedule was quite flexible however, and the students were frequently exposed to four or five periods of science instruction. If the teacher determined that the students were actively engaged in developing a particular concept they were allowed to pursue their interests in that topic. This teacher provided her students with a learning experience based on a constructivist view of learning and one that relied on the students' developing ideas as the driving force for her selection of instructional activities.

"Briefly, from a constructivist perspective, I perceive learners as actively constructing their own knowledge by using their existing knowledge to interpret new information in ways that make sense to them. As a result, learners build their own conceptual structures which subsequently fosters the development of some conceptions and inhibits the development of others" (teacher's written statement of her Philosophy of Teaching, produced as a requirement for a national science teaching award). In addition, she commented that she felt no obligation to cover a given amount of content in any discipline since she could begin the next school year where she left off the previous year (teacher, personal communication).

The teacher in this classroom gave considerable attention to helping her students develop an understanding of the developing conceptions they had and why they needed to be able to talk about those conceptions. The following is a list of this teacher's learning goals as presented to her students:

1. Can you state your own ideas?
2. Can you talk about <u>why</u> you are attracted to your ideas? ("the what as well as the why")
3. Are your ideas consistent?
4. Do you realize the limitations of your ideas and the possibility they might need to change?

5. Can you try to explain your ideas using physical models?
6. Can you explain the difference between understanding an idea and believing in an idea?
7. Can you apply intelligible and plausible to your own ideas?

Students in their first year of elementary school are presented with goals one and two and additional goals are added until by fourth grade the students are aware of all of the goals that will form the basis for the intellectual environment in this classroom. Enactment of these learning goals and evidence from the classroom discourse will be identified in the following data analysis. This teacher also provided the students with a means of commenting on the status of their conceptions as has been described elsewhere (see Hennessey, 1991).

Evidence for the teacher's learning goals

Implicit in these stated goals are some fundamental metacognitive activities. First among these metacognitive activities is the recognition of your ideas and that you need to be able to communicate your ideas to others (i.e. Can you state your own ideas?). The teacher reminds the students that they do have ideas and that they need to be able to comment on their ideas at the beginning of the year and periodically throughout the school year as indicated in the following:

> t: . ok . um . do you have ideas/ . can you talk about them/ . . bring them out into the open . um . why do you like your ideas/ . why you're attracted to them/ . you know . the what's as opposed to the why's

Table 1

Artifacts of transcription

t: = teacher speaking
s: or s's: = unidentified student or students speaking
r: = researcher speaking
/ = rising inflection indicative of a question
. or . . = pause of two seconds per period
[ ] = comments added by researcher to clarify the discourse
< > = short statement interjected into a longer segment of discourse

This approach to eliciting students' ideas goes beyond the mere propositional statement of an idea to providing some indication of the reasons students' gave for believing the idea. Thus it

is not simply a matter of having students identify their ideas as propositional statements nor is it a matter of the teacher determining the number or variety of conceptions expressed by students in her classroom. Although she does know this information, she is more interested in students determining the reasons behind their ideas and the status of their conceptions. For example, the statement - "Tables can exert a force" - by itself tells little about the reasons underlying this statement or it's status to the speaker. This statement may be intelligible, plausible, fruitful or some combination of these to the student. What is critical for the learner as well as the teacher and the researcher is to accurately determine the status of a conception and status can be determined only from comments about a conception (Hewson & Thorley, 1989 p. 550). If the statement "Tables can exert a force" is intelligible, the student must understand the words and the idea represented by the words, unintelligible statements necessarily resulting in the student not being able to psychologically represent the conception at all (Thorley, 1990). However, there is no evidence one way or the other as to whether the speaker finds the idea of tables exerting forces intelligible or not. If, on the other hand, the student finds the statement plausible - why does the student believe that tables can exert forces and are tables merely one object in a class of inanimate objects that can exert forces? Does the student have some causal mechanism in mind that supports their belief or is this a metaphysical belief about the nature of tables or solid surfaces in general? This statement might also be interpreted as fruitful if the student communicated that tables are only one class of objects capable of exerting force without a concomitant result of that force (i.e. a motion). What is necessary in order to determine the status of the statement "Tables can exert a force" is an indication from the student of the commitment they have to the idea and some reasons for their belief in the idea.

In addition to status related interaction (Thorley, 1990), statements indicating various components of the learner's conceptual ecology need to be elicited. Conceptions survive and have meaning in the conceptual ecology, as pointed out by Hewson and Thorley (1989), and the

various components of the ecology can be mapped onto the "conditions of an accommodation" (Strike & Posner, 1985, p.217). From a teaching point of view, information regarding the conceptual ecologies of learners' can be useful in planning instructional activities that enhance the possibility of creating dissatisfaction with existing conceptions. On the other hand, from a research point of view, investigating the conceptual ecologies of learners provides a much clearer indication of the knowledge structures of the learner and the learning process. In short, teachers must be able to produce the kind of discourse that makes public the conceptual ecologies of learners.

Instructional activities in this classroom were designed to facilitate public reflection by the students. For example, having developed shared definitions for the terms of the Conceptual Change Model (e.g. intelligible and plausible in this case) these students then applied their understanding of the terms throughout the balance of the course. In the following excerpts from classroom discourse the students indicate their ability to use the language of the Conceptual Change Model, in written format (see Table 2), and their ability to use their conception of intelligibility and plausibility when discussing the forces that might be acting on a book at rest on a table (see Table 3).

Table 2

Two students' joint definition of intelligibility

> When you explain your idea the words and sentences have to make sense. You can talk, draw, and write about your idea. Understandable and make sense have basically the same meaning. You can talk about your idea with models. When you explain your idea it has to be clear so other people can understand and make some sense with it. You can use models and analogies to represent your ideas. Your idea has to be consistent in the same situation. You can use your experiences to build your ideas. Before you can build your ideas you have to have a frameworking [sic] or a basic understanding of it. If you explain your idea by using models they have to be clear, or make sense to other people. Your explanation has to be understandable to other people.

Table 3

Students use conception of intelligibility in reference to their own thoughts

t: what would you need to know . in order to find out what's a better explanation . you know . what are some of the things you might need to know/

Rob: what those arrows mean

t: ok . so we need to know something about arrows

Bruce : what you are going to let [the arrows] stand for

t: ok so about the arrows . what other things would you need to know besides arrows

Kirsty : you would have to know like what each picture is telling you

t: ok you've got some pictures here that are trying to say something . you need to interpret pictures I guess

Student uses conception of plausibility

t : so in one sense that is pretty important . what about books/ what about tables/ what do you know about them/ . if you sort of refuse to consider them you're probably not going to get very far . because that's all you are really dealing with is the table and the book . and what do these arrows stand for/ . there isn't anything else in this picture [a picture of a book on a table with two equal and opposite force arrows]

Bruce : can I ask you a question/ <t: yes> what if you don't believe any of those/

t : oh . you don't think that any of those are a good explanation for what is going on/

Bruce : um huh [no I do not]

One student restates another student's idea, making it intelligible to the teacher

Bruce : yea because gravity is effecting on me that it would kind of make me lighter

t : so gravity is making you lighter/ [a question about a causal mechanism]

Bruce : yes

t : on the moon/

Kirsty : well see . I think I understand what Bruce was saying . I think he was saying that when you are here on Earth gravity . there is more gravity on Earth so it has a greater effect on you . pulling . and then the Moon is not as much gravity so it's not pulling as much

In each instance where students presented their ideas on a topic the teacher wanted to know why that idea was appealing to them. Over an extended period of doing this the teacher was able to determine the conceptions held by the students and which component(s) of the conceptual ecology these students were relying on to justify their conceptions. For example, when these students were discussing the particulate nature of water it became apparent that, to the students, different shapes of frozen water contained molecules of different shapes as well (i.e. a cylinder of frozen water had differently shaped water molecules than a 'honeybear' of frozen water). A complete transcript of the significant discourse recorded during this lesson can be found in Appendix B. The teacher inferred from the students' responses that 1) they were not able to separate a microscopic view of water molecules from a macroscopic view of frozen water and 2) they were inconsistent in the way they thought about water molecules, as will be shown in the following discourse analysis. The teacher chose to address these two conceptual problems with a series of instructional activities intended to challenge the students' existing conceptual knowledge. By selecting teaching activities that focused the students' attention on the macroscopic - microscopic distinction, in this case crushing a sugar cube into smaller and smaller pieces and then using a bridging analogy (Clement, 1987) to differing volumes of water, the students began to make a distinction between the two levels of description. However, these students still had to overcome an inconsistency in their thinking - specifically that there could in fact be differently shaped water molecules in each container of frozen water.

t: some of you were having difficulty with that . the water is coming from different places . on a macroscopic level . a large level that you can see with your eyes obviously it looks very different . the Yahara [River water] doesn't look like the drinking fountain water <s: I hope not> ok . but when we went down to the

microscopic level you said things but do you really believe what you said/ . what did you say about the microscopic level/ . . what about the microscopic level of water from a lake/ . what is it made out of/

s: H two O

t: something like that [writes chemical formula - H_2O] . ok what about the Yahara then/

s: H two O

t: ok . and whatever . drinking fountain or whatever . but you weren't satisfied . . . you were kind of like uncomfortable . I could see where you were coming from alright . and maybe I need to address that before addressing this . . where are those little ones/ [teacher gets colored fluff balls] . . . . . ok . let's say this is the drinking fountain water [two white fluff balls and one red in a vee shape] . ok . alright . do you agree that it is a good model for the drinking fountain water/ <s's: yes> . what if we are going to talk about the Yahara/

s: put some dirt in there . put some more water in there . [students suggest using colored fluff balls to represent contaminants to the water - green for garbage, brown for dirt, yellow for "body pollution" (urine)]
t: ok . so what is the basic part of the water/

s's: H two O

At this point the students indicate their understanding of the molecular composition of water as containing one part oxygen and two parts hydrogen. The fluff ball models of water used by the students in this lesson are consistent with canonical views of science and they are internally consistent for the students. However, they are unable to apply their molecular model to a macroscopic level of description when discussing water frozen in various shapes. The teacher indicates her understanding of the conceptual difficulty being experienced by the students in her statement, "I could see where you were coming from alright . and maybe I need to address that before addressing this." The "that" referred to here is the students' initial idea that water molecules could be different depending on the source of those water molecules. She addresses this potential problem by examining the students' views on the composition of water, all of which were made up of the same components for these students - H two O, and then confronting their views that water from different sources might be different at the molecular

level. In effect, she has confronted the students' metaphysical belief in the composition of water molecules and challenged them to apply their model in a consistent manner to water taken from any source. The following segment of transcript illustrates this teacher's ability to create dissatisfaction and call for consistent reasoning as these students think about frozen water as compared to liquid water.

> t: but the water is still there . alright . it doesn't mean that all the rest of the stuff can't be . you know things as big as a whale and as small as phytoplankton
>
> s's: take out the [colored fluff balls not representing water]
>
> t: is this the water/ [holds up a fluff ball not representing water]
>
> s's : no
>
> t: ok . so I take out everything that is not water . . ok . even if I did the same thing with models of the Yahara, models of the ocean, models of the drinking fountain, models of the swimming pool . if I take out everything not classified as water . then all the rest of the stuff has to come out . now some how some way when you are dealing with water you are ok but when we turn this stuff back to ice you get lost . . <s's: huh [an expression of puzzlement]> . ok . what is the difference between a solid and a liquid/
>
> s: solid is hard a liquid is runny
>
> t: ok . is this a solid or a liquid/ [model of water with molecules arranged in rows]
>
> s: solid
>
> t: ok . now what if I said this is drinking fountain frozen water . is that alright/
>
> s's: yes
>
> t: ok . what if said now this is drinking fountain frozen water/ [model of water with molecules arranged in a circle]
>
> s's: no . no
>
> t: what if I said that [circular representation] is drinking fountain frozen water/
>
> s's: no
>
> r: why isn't that one [a good model]/

Jane: because she said one was water and that was like in a straight line and now she says that they are in a circle and that's water too

r: what has to be the same Jane/

Jane: well if they're [both water they have to be the same]

r: ok . so whether it's water from the drinking fountain or water from the Yahara and it is frozen it has to be the same/

Jane: yes

t: ok . does it really make any difference . this way [linear representation] or the circle or the way I had them before/ <s's: yes> . yeah they are different models . but could all three of them be the explanation of frozen drinking water/ . what do you think/ . could this be a model of frozen drinking water the circle/ . ok . if I really believe that this is what frozen drinking water looks like . and then tomorrow when you come in here I say this is what frozen drinking water looks like [presents an alternative model] . . ok . alright . and the next day you come in here I say well this is what frozen drinking water looks like [presents a third model] . what is going on here/

s: it is not constant . you are not consistent in what you are saying

t: I'm changing what I'm saying/

These students are indicating their ability to apply consistent reasoning to their thoughts and to recognize inconsistent reasoning in the thoughts of others. In this instance adding the qualifier of frozen water, from any source, challenges the conception of water developed in the preceding segment of the class. The students are now able to generalize their conception of molecular water to include water from any source and in both states, solids and liquids.

In the example described above the students' views of water at the molecular level were initially inconsistent and idiosyncratic. The teacher responded by asking them to refer back to the physical models they had built of water molecules, all of which would be recognized as acceptable to the scientific community. When asked how water molecules were different in the various frozen shapes the students indicated that the arrangement of the molecules was different and they used multiple molecular models to illustrate their conceptions of how this could happen, failing to recognize that the molecular structure itself was consistent. Having

previously worked on the macroscopic - microscopic distinction the teacher asked the students if they were thinking about the macroscopic or the microscopic level of description. After considerable discussion about water and water molecules, tables and "table" molecules, air and "air" molecules, the students agreed that water molecules must be the same shape on the microscopic level, a metaphysical belief, but they can be arranged in many ways to produce the macroscopic shape we see. This distinction allowed the students to retain the view of water they had as represented by the model, that is hold a consistent view of water at the molecular level, and it allowed them to see the power in generalizing their view of water at the molecular level to cover a wide range of macroscopic phenomena (i.e. all water is the same on the molecular level regardless of the source of that water). These students were reflecting on specific components of their conceptual ecologies; 1) the role of images (as represented by the models) and 2) metaphysical beliefs in the composition of water, and 3) the function of epistemological commitments - consistency in reasoning with a model you have constructed and generalizability of that model to phenomena other than those for which the model was specifically constructed. Consistency and generalizability are two forms of epistemological commitments identified by Hewson (1985, p. 171).

Students in the above example met many of the learning goals established by this teacher. The students discussed their ideas and the reasons for those ideas (goals 1 & 2). They built physical models that represented their ideas and that provided a powerful means of thinking about water at the molecular level (goal 5). They recognized the limitations of their ideas, especially when inconsistency was pointed out to them, and the possibility that their ideas might need to change (goals 3 & 4). The teacher in this case started with the ideas that the students brought to the lesson and consciously planned activities that would address the conceptual problems these students would experience if they were to find the canonical view of water molecules plausible. Choosing a level of description to focus on, the teacher was able to address

components of the students' conceptual ecologies that required the students to reflect on the reasons for their beliefs (i.e. the use of exemplars, metaphysical beliefs, and epistemological commitments). For the students, recognizing the limitations of the conceptions they held and the inconsistency with which they applied that conception created the dissatisfaction necessary to a facilitate a conceptual change. But even with all of these gains the teacher still did not know if these students were committed to their stated descriptions of water at the molecular level. The students may have found their current conception of water molecules to be intelligible but not plausible. In contrast to the students in the Baird and Mitchell example cited previously, these students did engage in metacognitive reflection as they constructed their understanding of the science content. This distinction is one between ways of knowing, in the PEEL example, and ways of learning, as represented in the discourse of the classroom described in this study.

What was needed at this point was for the students to comment on the status of their conceptions. Hennessey's (1991) work has illustrated that students can apply the language of the Conceptual Change Model to their ideas. Following a very similar process, the students in this classroom developed shared definitions for the terms intelligible and plausible. The students were asked to describe their thoughts on force and motion and to comment on the intelligibility and plausibility of their ideas. From this information the teacher determined the degree of commitment that a particular student had to a conception. It is also worthwhile to note that the students applied the language of the model when talking to one another- telling a classmate that they find an idea intelligible but not plausible, or when trying to understand another student's idea (i.e. that they find the idea unintelligible which often results in questions such as 'could you explain what you mean by ...' or 'I understand the words you are using but I don't understand the idea.').

> Kirsty: . . ok at rest and moving at a constant speed in a straight line/ <t: yes> I don't get like what well they mean [the person speaking]. I get like what the sentence means but I don't know if

she means like at rest would be just like set it there or if you like throw it and it would just be at rest . I don't get it

t: yes . obviously then you have to say what does [at rest] mean/ because like any definition a definition's just words . and I could write a definition for what motion is . but it would just be words

The classroom events described above are indicative of the instructional activities used by this teacher to engage her students in metacognitive activities that facilitate their conceptual knowledge development and to allow her to monitor these developing conceptions. The teacher in this case was extremely sensitive to the notion that students interpret phenomena in a way that makes sense to them. She constantly sought to create an environment in which any student could present an idea in any stage of development without the fear of ridicule from their classmates. This was accomplished by an unstated 'rule' that no one could comment on the plausibility of another student's idea until everyone gave some verbal or nonverbal sign that they knew what the idea was that the speaker was talking about.

t: we're working here . . first of all listen to the group that's talking . see if you understand what it is they're talking about. If you don't understand what kind of questions do you need to ask in order to understand . forget about do you agree with it . you need to understand it first . alright/ . once you can understand what it is they're talking about and you happen to disagree that's alright but you need to understand what's going on here first okay/ . so you don't want to sort of jump in and say . "I disagree" . you don't even know for sure what it is they're talking about. so perhaps if you don't see it the same way you might want to ask some questions as to why they think that's the way of describing the forces . now remember everybody getting up here is possibly trying to describe what they think is the best way the best explanation for that activity . you may disagree with it . so in some sense you probably want to find out why do they think that's a good explanation . ok/

She was successful in that these students came to accept their role as one of finding the plausibility inherent within their own ideas first, and when considering an idea proposed by someone else these students needed to comment on the intelligibility of that idea before they indicated what they thought of the idea. Therefore, each student needed to find an idea presented to them intelligible prior to commenting on the plausibility of that idea.

Implications for planning conceptual change instruction emanating from this research are that the teacher must have a firm grasp of the conceptual problems likely to be experienced by students as they learn science content. Issues of historical importance to developing canonical views provide some clues as to potentially problematic areas for scientists and students of science alike. In a classroom of students learning science content for the first time it is equally, if not more important, to examine the reasons underlying stated ideas and to assess the level of commitment a learner has to a conception. Therefore, discourse related to status and the conceptual ecology can provide teachers with the information they need when planning lessons that address the students' conceptual knowledge development. In this classroom the teacher created dissatisfaction not with the science content per se but with components of the students' conceptual ecologies.

The implications of this approach for conceptual change instruction are that the teacher relinquishes (some) control of the science content in order to facilitate the developing conceptions of the students. It is the students' developing conceptual knowledge, as indicated by their ability to talk about their conceptions and the status of those conceptions, that the teacher uses in planning instructional activities. In this example the students failed to distinguish between the levels of description they were discussing and were inconsistent in the reasoning they applied to examples of frozen water at the molecular level. The teacher responded to these problems by planning her instruction to address components of the students' conceptual ecologies - namely consistency and generalizability. Relinquishing control of the content in this case does not imply that any answer given by the students, however dubious, is acceptable. The point is that the students need to identify, through their comments and their ability to reflect on their conceptions, why they believe their conceptions to be 'true'. The teacher then needs to be aware of this reasoning and adjust her instruction to challenge components of the learners' conceptual ecologies that might influence a change in a conception. In the end, canonical views of

science were constructed by these students but only after they had been challenged to explore the limits of their existing conceptions.

Conclusion

The single example presented above is indicative of a classroom environment that facilitates conceptual change learning. Students' ideas are exposed, as in many previous forms of conceptual change instruction, but this teacher then sought to encourage reflection about conceptions through a series of instructional activities designed to 1) address the science content and 2) have students actively comment on their justifications for and the status of their conceptions. These instructional activities are consistent with the basic tenets of the Conceptual Change Model - the conceptual ecology provides the context within which conceptions survive and have meaning and the status of a conception is an indication of the commitment an individual has towards a conception. Students' responses to these types of instructional activities can be evaluated by the teacher for science content knowledge as well as for components of the learners' conceptual ecologies that may be problematic and can be addressed by planning instruction to address both. Finally, the level of commitment attached to a student's conception can be determined as he or she comment on the status of their conceptions. This information can be used to address students' content knowledge as well as their abilities to think and talk about their conceptions, two significant aspects of effective conceptual change instruction.

Classrooms that facilitate the kind of intellectual environment suggested here provide researchers with a rich source of data concerning the conceptual ecologies of learners'. Although it has been suggested that the conceptual ecology identified in the existing Conceptual Change Model need to be expanded (see Duit, Goldberg & Niedderer 1992, Strike & Posner 1992, West & Pines 1983), careful analysis of student discourse from classrooms like the one described here may provide evidence of additional components suggested by various researchers. The ability to ask and answer questions about the conceptual ecologies of learners will provide

researchers interested in the practical aspects of conceptual change learning with an enhanced understanding of conceptual knowledge development. In addition, research on the ecology can provide those interested in theoretical aspects of the Conceptual Change Model with verification of psychological or philosophical constructs. It can be anticipated that as our knowledge of concept development in learners advances, the Conceptual Change Model itself will need to change.

APPENDIX A

Sequence of instructional activities (center column), conceptual issues with the science content (left column) and potential student discourse indicative of conceptual knowledge (right column) taken from unit on force and motion. Presented in a time ordered sequence with initial lessons at the top.

Conceptual considerations related to science content	Instructional activity presented to students	Student comments indicative of conceptual knowledge
explicit separation of cause from effects	Observe "Circus of Physics" demonstrations	intuitive conceptions of force and motion
strict limitations on which motions to observe	describe motion that makes sense to you	
	sort demonstrations for speeds up/slows down	students distinguish between conditions of at rest and steady pace
	sort demonstrations 4 ways: 1) change direction 2) change speed 3) at rest 4) steady pace	
draws distinction between natural motion and non-natural motion	sort demonstrations for natural motion	
	label forces with arrow diagrams	unbalanced forces cause a change in motion, balanced forces do not change motion
change in motion requires a cause	book on a table used as an exemplar	

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APPENDIX B

Complete transcript of the 'water molecules' discussion.

t: some of you were having difficulty with that . the water is coming from different places . on a macroscopic level . a large level that you can see with your eyes obviously it looks very different . the Yahara [River water] doesn't look like the drinking fountain water <s: I hope not> ok . but when we went down to the microscopic level you said things but do you really believe what you said/ . what did you say about the microscopic level/ . . what about the microscopic level of water from a lake/ . what is it made out of/

s: H two O

t: something like that [writes chemical formula - H_2O] . ok what about the Yahara then/

s: H two O

t: ok . and whatever . drinking fountain or whatever . but you weren't satisfied . . . you were kind of like uncomfortable . I could see where you were coming from alright . and maybe I need to address that before addressing this . . where are those little ones/ [teacher gets colored fluff balls] . . . . . ok . let's say this is the drinking fountain water [two white fluff balls and one red in a vee shape] . ok . alright . do you agree that it is a good model for the drinking fountain water/ <s's: yes> . what if we are going to talk about the Yahara/

s: put some dirt in there . put some more water in there . [students suggest using colored fluff balls to represent contaminants to the water - green for garbage, brown for dirt, yellow for "body pollution" (urine)]

t: ok . so what is the basic part of the water/

s's: H two O

t: ok . is this water/ [holds up brown fluff ball]

s's: no

t: is this water/ [holds up green fluff ball]

s's: no . that's garbage

t: is this water/ [holds up yellow fluff ball]

s's: [some no's some yes - students giggle about whether urine is water or not]

t: what if it was the [water in the] ocean/

s's: put some salt in . it would have whales

r: what is the same about this water/

s: it has H two O

r: it has H two O in it

t: ok . we are talking about the ocean . what needs to change anything/

s: it has oil in it

t: ok . how many drops of oil in it/

[confusion about adding whales, fish, etc. but one student is heard to say about the water "it is the same molecule"]

t: but the water is still there . alright . it doesn't mean that all the rest of the stuff can't be . you know things as big as a whale and as small as phytoplankton
s's: take out the [colored fluff balls not representing water]

t: is this the water/ [holds up a fluff ball not representing water]

s's : no

t: ok . so I take out everything that is not water . . ok . even if I did the same thing with models of the Yahara, models of the ocean, models of the drinking fountain, models of the swimming pool . if I take out everything not classified as water . then all the rest of the stuff has to come out . now some how some way when you are dealing with water you are ok but when we turn this stuff back to ice you get lost . . <s's: huh [an expression of puzzlement]> . ok . what is the difference between a solid and a liquid/

s: solid is hard a liquid is runny

t: ok . is this a solid or a liquid/ [model of water with molecules arranged in rows]

s: solid

t: ok . now what if I said this is drinking fountain frozen water . is that alright/

s's: yes

t: ok . what if said now this is drinking fountain frozen water/ [model of water with molecules arranged in a circle]

s's: no . no

t: what if I said that [circular representation] is drinking fountain frozen water/

s's: no

r: why isn't that one [a good model]/

Jane: because she said one was water and that was like in a straight line and now she says that they are in a circle and that's water too

r: what has to be the same Jane/

Jane: well if there [both water they have to be the same]

r: ok . so whether it's water from the drinking fountain or water from the Yahara and it is frozen it has to be the same/

Jane: yes

t: ok . does it really make any difference . this way [linear representation] or the circle or the way I had them before/ <s's: yes> . yeah they are different models . but could all three of them be the explanation of frozen drinking water/ . what do you think/ . could this be a model of frozen drinking water the circle/ . ok . if I really believe that this is what frozen drinking water looks like . and then tomorrow when you come in here I say this is what frozen drinking water looks like [presents an alternative model] . . ok . alright . and the next day you come in here I say well this is what frozen drinking water looks like [presents a third model] . what is going on here/

s: it is not constant . you are not consistent in what you are saying

t: I'm changing what I'm saying/

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